UCRL- 92519
PREPRINT

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This paper was prepared for submittal to
11th Symposium on Fusion
Engineering Proceedings
Austin, Texas
November 18-22, 1985

November 11, 1985

Lawrence Livermore National Laboratory

PLASMA-POTENTIAL DIAGNOSTIC (PPD) HARDWARE USED ON THE TANDEM MIRROR EXPERIMENT-UPGRADE (TMX-U)

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Abstract

The PPD is an instrument used to indirectly measure the potential of the center-cell plasma of TMX-U. Thallium ions are injected at energies of about 60 keV from an ion gun capable of 80 kV operation. The singly charged ions collide with plasma electrons and generate double-charged ions. Ions in the higher charge state exit the plasma and are detected in an electrostatic energy analyzer. From measurements of the injected ion energy and the output ion energy one can determine the plasma potential in the ionization region. The absolute potential measurements required careful calibrations of the energy analyzer.

This paper will discuss hardware and techniques for calibrating the energy analyzer on the PPD. Initially, calibrating the PPD analyzer required full operation of the TMX-U magnets to deflect the beam into the energy analyzer. Since it is a hazard to operate the magnets while personnel are in the pit area, calibration was done remotely. This was not only time consuming but also required magnet system operation personnel. The calibration of the PPD analyzer involves balancing the analyzer split plate currents and measuring the analyzer and accelerator potentials.

A calibration system for the PPD was installed on TMX-U in December 1984. Here the ions are injected at a well defined angle into the energy analyzer. This eliminates the need to run the magnets to calibrate the energy analyzer on the PPD.

"Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48."

Introduction

The Plasma-Potential Diagnostic (PPD) is an instrument used to indirectly measure the potential of the center-cell plasma of TMX-U. Thallium ions are injected at energies of about 60 keV from an ion gun capable of 80 keV operation. The singly charged ions collide with the center cell plasma electrons and produce multiplely ionized atoms. Ions in the higher ionized state exit the plasma and are detected in an electrostatic energy analyzer. From measurements of the potential energy of the injected and exiting ions, one can determine the plasma potential. The absolute potential measurements require careful calibrations of the energy analyzer system and Thallium ion injection system. The hardware used to achieve initial potential measurements consist of components similar of those used on TMX by G. Hallock [1]. Component modifications were made to improve the system operational parameter range. Figure 1 shows the locations of the ion gun, the energy analyzer, and the primary beam detector for the PPD used on the TMX-U.

Ion Energy Analyzer

The mechanical configuration is an upgrade of that used earlier. The Energy Analyzer is a parallel plate electrostatic deflection analyzer which measures secondary ion energy and current. A schematic of the TMX-U analyzer is shown in Figure 2.

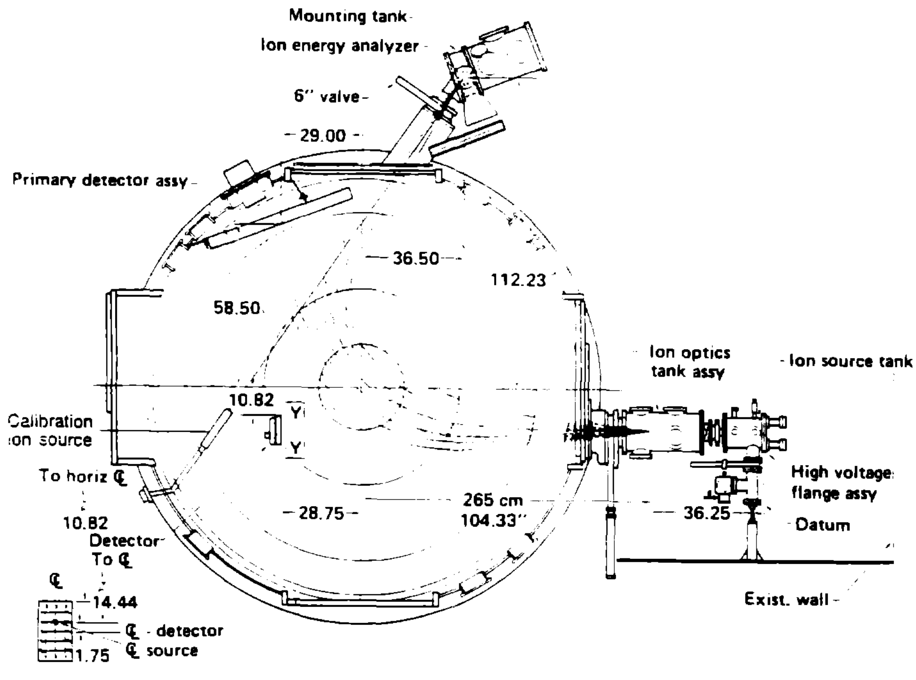
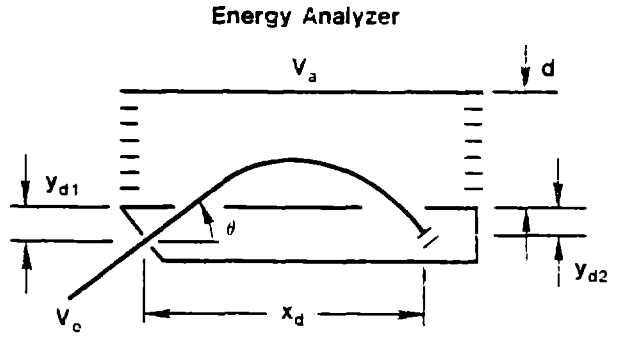


Figure 1. Hardware Layout of the Plasma Potential Diagnostic on TMX-U.



$$\text{Gain} = \frac{V_o}{V_a} = \frac{x - (y_{d1} - y_{d2}) \text{Cot}\,\theta}{2\, d \sin\theta \cos\theta}$$

Figure 2. A Simplified Representation of the Energy Analyzer.

The distance from the entrance slit to the detector plates, Xd, is adjustable from outside of the vacuum system. The entrance slit width is also adjustable externally. Finally, the angle of the analyzer with respect to the exiting ion beam is adjustable from outside vacuum.

In order to improve the accuracy of the analyzer system, several mechanical modifications were made. Design changes were made in the entrance slit drive mechanism which reduce slit setting uncertainties. In addition, the mounting structure for the split plate holder and drive mechanism were replaced with a more rigid and accurate mounting structure. The above changes reduced the overall mechanical system parameter uncertainties by an order of magnitude.

Four split plates monitor the position of the secondary beam. The beam position is related to the ion energy. The split plate front end transresistance amplifiers are mounted within the base of the analyzer. This reduces the noise problems which would occur if the nanoampere signals were fed through long cables and the vacuum wall to external amplifiers. Early amplifiers had temperature drift problems and a noise level of about 1 nanoampere with a transimpedance of 10^6 ohms. Replacement amplifiers were designed with a 200 picoampere noise limit and substantially improved drifts. The new amplifiers operate at a transimpedence of 10^7 ohms and permit satisfactory operation of the system in plasma densities above 10^{11} atoms/cm^3.

To avoid aliasing the data in the relatively slow digital recorders, the bandwidth of the system is limited by filtering to 20 kHz. A Spellman (RH30p150) 30 kV supply is used to drive the analyzer top plate. It has a current output (5 ma) which should maintain the analyzer voltage under moderate plasma loading. The original buffer amplifier and A/D converter system was replaced with commercial digital voltmeter. This upgrade improved the reliability and resolution. With above changes, the relative energy resolution is approaching 25 volts.

Deflection System

The beam deflection plates are located in an optics tank which couples the gun tank to the TMX-U vessel (Fig. 1). The original Z deflection system contained Trek 604 sweep amplifiers driven by a high impedance input operational amplifiers. When running the gun at higher voltages, system breakdown would damage the high impedance amplifiers. To improve the system reliability, two Trek 609-1 and two 608 are now used for the beam sweep power supplies. The 609-1 has a gain of 500 and is capable of delivering 0 to $\pm$2.5 kV for the Z sweep. The 608 has a gain of 500 and is capable of delivering 0 to +5 kV for the Theta sweep. Drive for the sweep power supplies is a CAMAC programmable function generator. The computer software programs the CAMAC modules and provides linear deflection of the beam over the required ranges. Use of the CAMAC programmable function generator permits more accurate and easily changeable deflection system parameters.

Primary Source System

The PPD ion gun was previously limited to operating voltages of 30-35 kV which limited plasma potential measurements to the TMX-U center cell running at 2 kG. TMX-U operation at 3 kG required an increase in the source capability. Source material and geometry modifications have been made and permit the source to operate up to 80 kV with current outputs up to 8 µA.

Operating at 60 kV has resulted in more frequent source arcing. Source arc down had frequently destroyed the in-house voltage measurement circuits used to monitor the high voltage of the gun and analyzer supplies.

Primary Beam Detector

This is a position measuring detector located on the top of the TMX-U central cell. It is used to monitor the primary ion beam location as it is deflected by the TMX-U magnetic field through the diamagnetic plasma. The position (location) of the primary beam on this detector provides first order information on gun potential.

The detector consists of 64 rectangular copper bars arranged perpendicular to the incident beam. The bars are connected by resistors to form a linear current position detector. From current signals out each end of this array, beam position can be determined.

Control System

The PPD control system is based on standard CAMAC modules, commercial power supplies, and a local computer for system control and analysis of the data. The CAMAC system itself consists of three crates interfaced together through fiber optic serial link operating at five megabits. To minimize analog signal path lengths, two of the CAMAC crates are located in the TMX-U pit area.

Figure 3 shows the control crate and computer located in the diagnostic area of the TMX-U building. This control crate contains a Kinetic Systems 3938 fiber optic U-Port Adapter, a Kinetic Systems 3992 Serial Highway Drive and a Kinetic Systems 3988 Crate Controller. The U-port adapter provides a bit-serial highway path when used with the Serial Highway Drive. The D-port signal from the Serial Driver is transmitted by the U-Port through fiber optic cable to the auxiliary crates located in the TMX-U pit area. The crate controller provides an interface from the local computer to the control crate, via a GPIB interface.

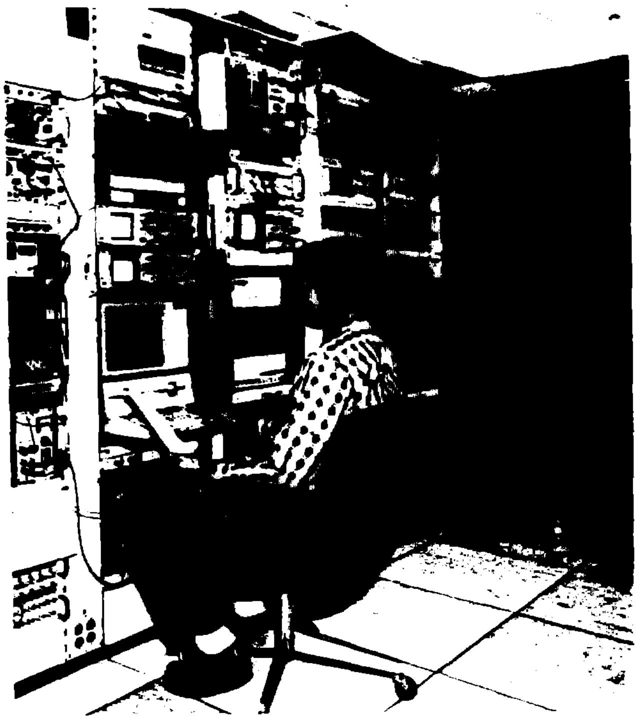


Figure 3. The Physics Operating Position for the PPD.

The analyzer crate is located in the analyzer rack on top of the TMX-U near the central cell of the machine. The analyzer system hardware provides for secondary signal recording and analyzer high voltage programming and monitoring. This crate contains a Kinetic Systems 3952 serial crate controller, a Kinetic Systems 3938 fiber optic U-Port Adapter, a LeCroy 8210 Data Recorder for signal recording, an in-house built 8-channel differential I/V for the primary beam detector, a Kinetic Systems 3112 DAC used for programming the power supply, and a Kinetic Systems 3388 GPIB Interface module used for reading the actual voltage from an H.P. Digital Voltmeter.

The Gun or Source crate is located in the TMX-U pit area. This crate controls three high-voltage power supplies and four high-voltage amplifier supplies. Its function is dedicated to the primary beam line and controls the ion gun and beam sweep. This crate contains a Kinetic Systems 3952 serial crate controller, a Kinetic Systems 3938 fiber optic U-Port Adapter, a Kinetic Systems 3112 DAC used for programming the power supplies, a Kinetic Systems 3388 GPIB Interface module used for reading the beam voltage from an H.P. Digital Voltmeter, a LeCroy 8601 Programmable Function Generator for deflection, and an in-house built Filament Controller for the filament of the gun.

The PPD computer system is a stand-alone Hewlett-Packard (H.P.) 9836 operating under the H.P. Basic 4.0 operating system. The entire Plasma-Potential Diagnostic is shown in a schematic in Figure 4.

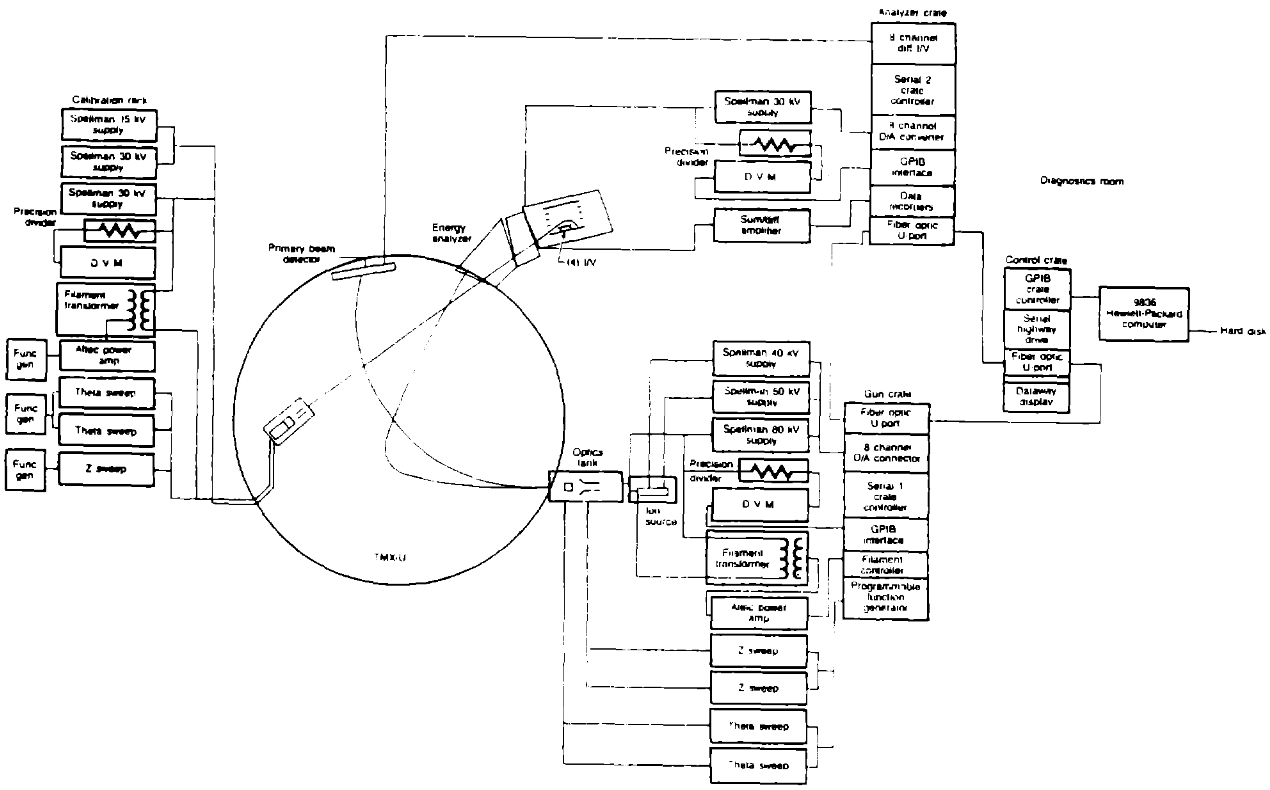


Figure 4. Plasma Potential Diagnostic System Block Diagram.

Calibration System

A calibration system for the PPD was installed on TMX-U in December 1984. Here the ions are injected at a known angle into the energy analyzer. This eliminates the need to run the magnets to calibrate the energy analyzer on the PPD.

This system is manually controlled and consists mainly of the same components used to operate the ion gun on PPD. The system components are shown in Figure 4. The calibration system consists of a deflection system, a function generator to drive the deflection system, three high voltage power supplies for the ion gun, a 10,000:1 high voltage divider, a DVM to measure the gun voltage, and sweep supply amplifiers to drive the sweep plates. The calibration ion gun operates at a voltage of 15 kV without magnetic field versus 60 kV on the PPD ion gun.

Summary

Several upgrades and modifications have been made to extend the performance of the PPD and improve the system reliability. The present system operates up to 80 kV and obtains data in a 3 kG field with densities above 1×10^{11} atoms/cm^3.

References

[1] G. A. Hallock, Radial Space Potential Measurements in the Central Cell of TMX with a Heavy Ion Beam Probe, Lawrence Livermore National Laboratory, UCID 19759 (1983).

[2] R. S. Hornady, Summary of TMX-U Results: 1984, Thallium-Ion Beam Plasma-Potential Diagnostic (PPD), Lawrence Livermore National Laboratory, UCID-20274 (1984).